DESIGN AND ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM USING H_2O + [EMIM] [TFA]

A PROJECT REPORT SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

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By

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of
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CERTIFICATE

This is to certify that the thesis entitled **"DESIGN AND ANALYSIS OF ABSORPTION REFRIGERATION SYSTEM USING H_2O + [EMIM] [TFA]"** submitted by **Rajendra Kumar Senapati** in the partial fulfillment of the requirement for awarding the degree of **BACHELOR OF TECHNOLOGY** in **Chemical Engineering** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Dt. 7th May 2015

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Date Rajendra Kumar Senapati

ABSTRACT

With rapid industrialization and constantly increasing energy consumption, human kind is going to face a growing degradation of environment, if the activities continues as usual. This work is focused to design an absorption refrigeration cycle which gives solution to present cooling problems using low grade heat coming out from the industries. More importance has been given to the ionic liquid based working pairs which are eco-friendly in nature. Ionic Liquids (ILs) are polar compounds which are considered as a combination of organic cations and inorganic anions, and are liquid below 100ºC and have potential to replace common VOCs as solvents in chemical processes. ILs have many favorable attributes such as a low vapor pressure, stability over a large liquid working temperature range, and the ability to be designed to dissolve compounds of interest. This research redresses innovative solutions using ILs for absorption refrigeration cycle. Ionic liquids (ILs) are used as absorbents in absorption refrigeration systems, which present the possibility of overcoming some of the safety and environmental concerns of current systems. In general, absorption refrigeration is attractive since electrical energy is replaced with low grade heat energy. Many ILs are completely miscible with water, which leads the focus to investigate ILs and water for this application. Moreover, this research work aims at finding out the value of COP for H_2O + [EMIM] [TFA], to design an optimal absorption refrigerator and to study the dependence of COP on various parameters. It also carries out study on the economic feasibility of the absorption refrigeration cycle using H_2O + [EMIM] [TFA] working pair to compare with the conventional working pairs and compression refrigeration system. It further addresses the roadblocks in the simulation of the absorption refrigeration cycle using water and [EMIM] [TFA].

Keywords: Absorption Refrigeration Cycle, Ionic Liquid, VOC, Simulation

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ABBREVIATIONS AND SYMBOLS USED

IL → Ionic liquid

ABS → Absorption refrigeration system

b/w → Between

Q_g → Heat duty of the generator in kW

Q_e →Heat duty of the evaporator in kW

Q_c → Heat duty of the condenser in kW

Q_a →Heat duty of the absorber in kW

x_g → Composition of strong solution

x_a → Composition of weak solution

x_f → Composition of water in the solution of IL and water

m_s → Mass flow rate of weak solution. in kg/ sec

m_r → Mass flow rate of water in kg/ sec

$m_s - m_r$ → Mass flow rate of weak solution in kg/ sec

H → Enthalpy in kJ/kg

T_a →Temperature at the absorber in ˚C

T_e →Temperature at the evaporator in ˚C

T_c → Temperature at the condenser in ˚C

T_g →Temperature at the generator in ˚C

P_a → Pressure at the absorber in kPa

P_e → Pressure at the evaporator in kPa

P_c →Pressure at the condenser in kPa

P_g → Pressure at the generator in kPa

f → Flow ratio.

COP →Coefficient of performance

η →.COP

W_p →Work done by pump in kW

CHAPTER 1

Introduction and Literature Review

1.1 Introduction

In this study, ionic-liquids (ILs), which are salts in a liquid state usually with organic cations and inorganic anions, are used as an absorbent in an absorption refrigeration system designed for cooling requirements utilizing low grade heat of data centers, commercial installations, power plants etc. Due to the toxic and flammable nature of volatile organic compounds (VOCs), ILs with the negligible vapor pressure have been considered as a possible replacements of solvents for use as a solvent in absorption refrigeration cycle.

1.2 Absorption refrigeration cycle using H_2O + [EMIM] [TFA]

Absorption refrigeration has the ability to replace the electrical energy of a conventional vapor-compression cycle with low value heat energy. ILs have tunable properties, zero vapor pressure, and high thermal stability, ILs are promising absorbents. In particular, the low volatility of the IL enables easy separation of the volatile working fluid from the IL by thermal stratification with the minimum harmful impacts on environment. ILs can provide an alternative to the normally toxic working fluids used in some absorption systems, such as the ammonia/water system. In order to evaluate the IL and water systems for absorption refrigeration, the coefficient of performance is calculated. Therefore, enthalpies are needed at various places in the cycle. The enthalpy of the IL and water mixture is calculated from experimental heat capacity and excess enthalpy measurements. Additionally, vapor-liquid equilibria measurements are needed to calculate the activity coefficients which identify the systems deviation from ideality.

In the absorption refrigeration system, the refrigerant vapor water is absorbed in IL; the absorbent is then regenerated in the generator at higher temperature using low grade heat releasing the refrigerant water vapor. The water vapor then gets liquefied in the refrigeration loop finally reaches to the evaporator to get vaporized again by taking heat from the space to be cooled. The regenerated absorbent is sent back to absorber and again takes up refrigerant vapor. The absorption-generation is working like a chemical compressor, which is a replacement of electrically driven compressor of vapor-compression refrigeration cycle.

1.3 Literature survey

The vapor-absorption refrigeration cycle is more than 100 years old. Although the vapor-compression cycle has taken over most of air-conditioning and refrigerating applications, the well-known refrigerant–absorber systems (H_2O/LiBr and NH_3/H_2O) are still being used for certain

applications, particularly in the field of industrial applications or large-scale water chiller systems. Recently, more attention has been given towards the recovery of waste heat using the NH_3/H_2O system [1]. Besides these traditional binary-pairs, some pioneering studies were made to propose new refrigerant–absorbent pairs for the vapor-absorption cycle, using fluoroalkane refrigerants with organic absorbents [2, 3].

But as the working pairs mentioned above are volatile in nature, they are very difficult to handle and hence the search for a better working pair with favorable working temperature conditions is very much required. Moreover, we have to carry out fundamental research on these ILs to have a better know-how about those solvents. But, before going after the ILs, we must have a clear understanding of the vapor absorption cycle.

In order to understand the vapor-absorption cycle and to evaluate the cycle performance, thermodynamic property charts such as temperature–pressure–concentration (TPX) and enthalpy–temperature (HT) diagrams are required. These charts correspond to the familiar PH (pressure–enthalpy) or TS (temperature–entropy) diagram in the vapor-compression cycle analysis [4].

Then coming to the ILs, several working pairs have been dealt with and found to be potential replacement for the conventional working pairs.

The thermodynamic performance of an absorption chiller operating with water + [EMIM] [DMP] and mixtures has been compared under the same operating conditions by Zhang and Hu [5]. The coefficient of performance of the absorption chiller for working fluid [EMIM] [DMP] was lower than that of by 7% but still higher than 0.7.

Kim et al. [6] in one of their other studies have obtained the thermo physical properties of [EMIM] [BF4] with the saturation temperatures at the evaporator and condenser being 25°C and 50°C, respectively. A power dissipation of 100 W is estimated, while COP value of the system reaches 0.91.

Higher viscosity ILs cause an increased pressure drop in the compression loop, which would result in larger pumping power or larger pipes and system volume. The viscosity increases with cation mass: EMIM < BMIM < HMIM. The viscosity is more dependent on the anion with the following order: $Tf_2N < BF_4 < PF_6$.The viscosity of [EMIM] [Tf_2N] is only 31.3 MPa s at 294 K, which is 10 times smaller than that of [HMIM] [PF_6] [6].

Ionic liquids with longer cation alkyl chain length cause a larger solubility but lower dependence of the solubility on temperature [7, 8]. Thus, Ionic liquids with shorter alkyl chains in cation are preferred ([EMIM] > [BMIM] > [HMIM]) due to more sensitive dependence of the solubility on temperature.

High circulation ratio increases the energy requirements of heating and pumping processes. Circulation ratios in and systems usually are smaller, with typical values being around [9, 10].

ILs circulation ratios when compared to conventional absorption refrigerators are high. The lowest and hence the best circulation ratios observed ranged from 20 to 25 [11].

1.4 Objective and scope

Objective:

- ✓ Utilization of low grade heat using (IL+ water) based absorption refrigeration system.

Scope:

- Design and analysis of ([EMIM] [TFA] +H_2O) based absorption refrigeration system.
- Study of economic feasibility of ([EMIM] [TFA] +H_2O) based absorption refrigeration system.

1.5 Chapter layout

Chapter 1 deals with Introduction and Literature Survey

Chapter 2 describes the Theoretical Postulates on Absorption Refrigeration cycle using H_2O + [EMIM] [TFA]

Chapter 3 Simulation and Analysis of Absorption Refrigeration Cycle

Chapter 4 System Analysis and Economic Feasibility

Chapter 5 Conclusions and Future Recommendations

CHAPTER 2

Theoretical Postulates on Absorption Refrigeration Cycle using H_2O + [EMIM] [TFA]

2.1 Introduction to absorption refrigeration cycle

Generally, there are two types of refrigeration cycle, vapor compression refrigeration cycle and vapor absorption refrigeration cycle. Vapor compression cycle is the conventional one, which consumes a lot of electrical energy in which CFC's are used as refrigerants. For large quantity of electrical energy, large amount of fossil fuels have to be burnt and it will lead to more CO_2 emissions. Secondly, the working pairs used are toxic and corrosive in nature and also depletes the ozone layer. These factors raise more concern for environmental pollution and energy utilization with rapid economic growth and hence human beings have to face more and more serious environmental and energy issues. The ways to solve these problems are developing ways to utilize renewable energy resources, enhancing energy utilization efficiency and so on. Absorption chillers or absorption heat pumps are both important energy saving devices which can be driven by low-grade thermal energy, such as solar energy, geothermal energy and industrial waste heat from industrial process, so the devices will play an important role in improving energy utilization efficiency and reducing environmental pollution and carbon dioxide emissions. The absorption refrigeration technology has attracted much attention all over the world, for the reason that it is environmental friendly and could make use of the low-grade energy, which refers to the ignored energy embedded in the exhaust steam of low pressure and low temperature.

As, we now have the idea about the superiority of vapor absorption cycle over conventional vapor compression cycle, let us now explore the working pairs for the absorption refrigeration cycle. Before that let us have a clear idea about the differences b/w vapor absorption cycle and vapor compression cycle, which are discussed in the following section.

2.2 Differences between absorption refrigeration cycle and compression refrigeration cycle

- ✓ The most notable difference between these cycles is the way in which the compression work is done. In, vapor compression cycle, compression is done by using a compressor, which consumes a lot of electrical energy. Whereas in vapor absorption cycle, compression is done by using a generator-absorber solution circuit, which comprises of generator, absorber, heat exchanger and pump.

- ✓ Vapor compression cycle uses toxic and corrosive refrigerants where as in vapor absorption cycle we can use H_2O and ionic liquid based working pairs, which are eco-friendly in nature.

- ✓ In vapor absorption cycle, work input is low as pumping involves liquid whereas in vapor compression cycle, work for compression is very high.

- ✓ Even though there are more equipment in vapor absorption cycle than vapor compression cycle, vapor absorption cycle is economically justifiable as it uses low grade source of heat like solar energy, geothermal energy and other industrial sources of heat.

- ✓ Vapor compression cycle can be made to work at low pressure using certain working pairs whereas high pressure needs to be maintained for vapor compression cycle.

2.3 What do we mean by low grade energy?

Low grade heat energy refers to the energy derived from the renewable sources like solar energy or geothermal energy and the ignored energy from the industries, embedded in the exhaust steam of low pressure and low temperature, which cannot be used to do any work. It plays an important role in improving energy utilization efficiency and reducing environmental pollution and carbon dioxide emissions. The use of low grade thermal energy reduces the consumption of electrical energy to a large extent.

2.4 Working pairs

The cycle performance of refrigeration cycles depends not only on their configuration, but also on thermodynamic properties of working pairs regularly composed of refrigerant and absorbent. The commonly used working pairs in absorption cycles are aqueous solutions of either lithium bromide water or ammonia water. However, corrosion, crystallization, high working pressure, and toxicity are their major disadvantages in industrial applications. Therefore, seeking more advantageous working pairs with good thermal stability, with minimum corrosion, and without crystallization has become the research focus in the past two decades. To comply with the above properties, we look forward to ionic liquids(ILs**)** that have attracted considerable attention due to their unique properties, such as negligible vapor pressure, non-flammability, thermal stability, good solubility, low melting points, and staying in the liquid state over a wide temperature range from room temperature to about 300°C. The above mentioned favorable properties of ILs have motivated us to carry out our research on absorption refrigeration cycle using IL- based working pairs in which water is used as refrigerant and IL is used as an absorbent.

Requirements of working fluids of absorption cycles are as follows:-

i) The difference in boiling point between the pure refrigerant and the absorber solution at the same pressure should be as large as possible.

ii) Refrigerant should have high heat of vaporization and high concentration within the absorbent in order to maintain low circulation ratio between the generator and the absorber per unit of cooling capacity.

iii) Transport properties that influence heat and mass transfer, for example, viscosity, thermal conductivity, and diffusion coefficient, should be favorable.

iv) Both refrigerant and absorbent should be noncorrosive, environmentally friendly, and of low cost.

2.5 Ionic liquids

An ionic liquid is a salt in which the ions are poorly coordinated, which results in these solvents being liquid below 100°C, or even at room temperature (room temperature ionic liquids, RTIL's). At least one ion has a delocalized charge and one component is organic, which prevents the formation of a stable crystal lattice. Properties such as melting point, viscosity, and solubility of starting materials and other solvents are determined by the substituents on the organic component and by the counter ion. Many ionic liquids have even been developed for specific synthetic problems. For this reason, ionic liquids have been termed "designer solvents". The absence of volatility is one of the most important benefits of ionic liquids, offering a much lower toxicity as compared to low boiling point solvents as a result of which they are known as “green solvents”.

The ionic liquids generally are classified into 3 categories: ILs that are completely soluble in water, ILs that are partially soluble in water and the last category is the ILs that chemically complex with CO_2. In absorption refrigeration cycle, we will be using ILs of first category. Examples of ionic liquids of 1st category are as follows:

Table 2.1 Few Ionic Liquids along with their abbreviations

Abbreviation	Name
[EMIM][TFA]	1-Ethyl-3-methylimidazolium Trifluoroacetate
[OHEMIM][TFA]	1-(2-hydroxyethyl)-3-methylimidazolium Trifluoroacetate
[EMIM][EtSO4]	1-Ethyl-3-methylimidazolium Ethylsulfate
[EMIM][HSO4]	1-Ethyl-3-methylimidazolium Hydrogensulfate
[EMIM][OTf]	1-Ethyl-3-methylimidazolium Trifluoromethanesulfonate

Of all the above listed ionic liquids, I will be using [EMIM] [TFA] along with water as my working pair for the above sought absorption refrigeration cycle.

2.6 Working principle of absorption refrigeration cycle

The basic components of the absorption cycles are the evaporator, condenser, generator and absorber. While the evaporator is supplied with heat from the surrounding that need to be cooled and generator is supplied with waste heat from the industries at the same temperature. The increased heat is delivered from absorber and condenser is used to condense the refrigerant, which is water. The operating system of the absorption cycle is described as follows as per Figure 2.1.

Refrigerant vapor is produced at state 7 in the evaporator, by gaining heat from the surrounding that needs to be cooled. The refrigerant vapor dissolves with the strong refrigerant-absorbent solution that enters the absorber from state 3 and weak solution returns back to generator at state 1. In the generator some refrigerant vapor is removed from the weak solution to be sent to the condenser and consequently the strong solution from the generator is returned to the absorber. After condensing the vaporized refrigerant in the condenser, it is made to pass through an expansion valve before it enters the evaporator. The waste heat delivered to the evaporator causes its vaporization. Again the absorber absorbs the refrigerant vapor at a higher temperature. Therefore, the absorption cycles have the capability of raising the temperature of the solution above the temperature of the waste heat.

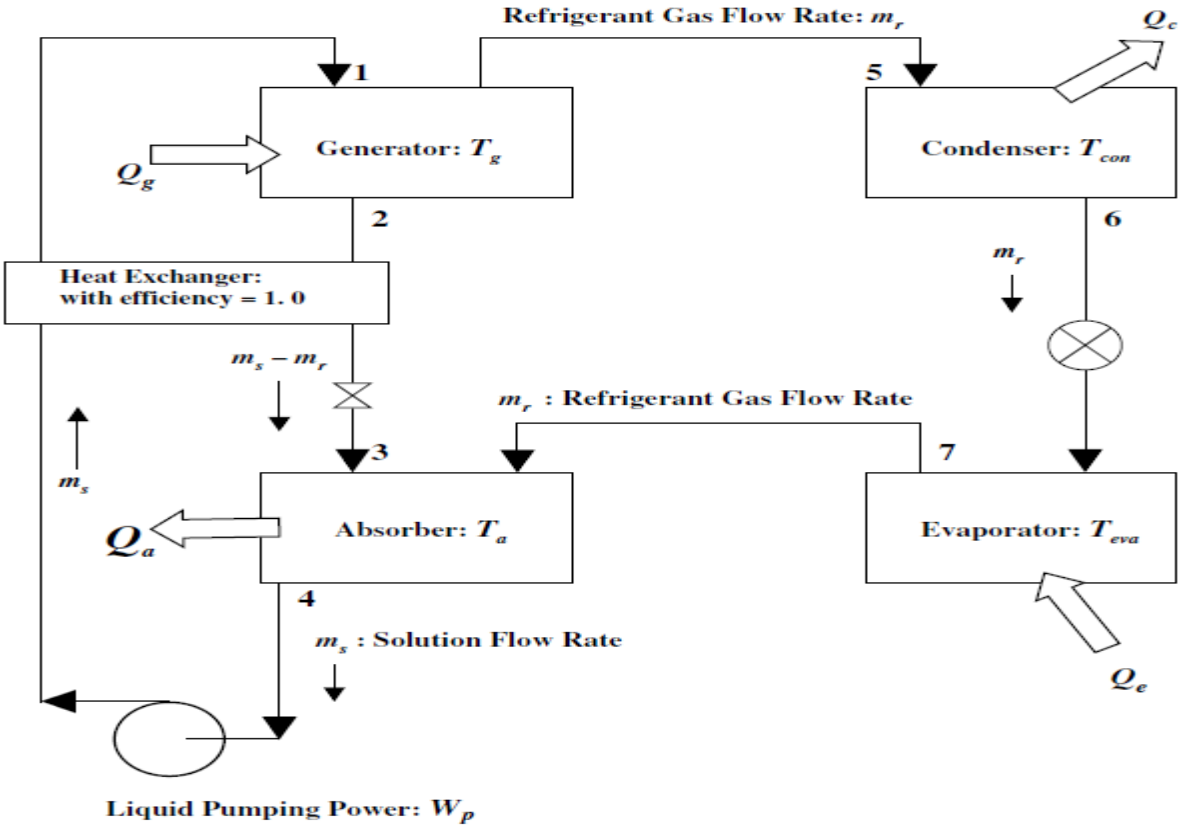

Figure 2.1 Schematic Diagram of Simple Vapor absorption Cycle

Like vapor compression cycle, it also four steps that completes the thermodynamic cycle, which are as follows:

i) Isothermal heat addition in the evaporator
ii) Chemical compression in an assembly of absorber; generator and pump
iii) Isothermal heat rejection of generated refrigerant in the condenser
iv) Adiabatic expansion of the condensed refrigerant in the expansion valve

2.7 Vapor absorption refrigeration cycle performance

A schematic diagram for a simple vapor-absorption refrigeration cycle used in the present study is shown in Figure 2.1. The system is composed of condenser and evaporator units with an expansion valve similar to an ordinary vapor compression cycle, but the compressor unit is here replaced by an absorber–generator solution circuit, which has a vapor absorber, a gas generator, a heat exchanger, an expansion valve, and a solution liquid-pump.

Theoretical Cycle performances are calculated in the following way. The overall energy balance gives the following equation:

$$Q_a + Q_c = Q_g + Q_e + W_p \quad (2.1)$$

From the material balance in the absorber or generator, we have

$$m_s x_a = (m_s - m_r)x_g \quad (2.2)$$

Mass flow ratio is an important parameter for determining the system performance, which is calculated as follows:

. Mass flow ratio, $f = m_s/m_r = x_g/(x_g - x_a)$ (2.3)

Now coming to energy balance around the generator, absorber, condenser and evaporator, we have the following equations:

$$Q_g = H_5 m_r + H_2 (m_s - m_r) - H_1 m_s \quad (2.4)$$

And from the assumption of unity for heat transfer efficiency in the heat exchanger, we have

$$(H_2 - H_3)(m_s - m_r) = (H_1 - H_4) m_s - W_p$$

$$\Rightarrow H_1 = H_4 + (H_2 - H_3)(1 - 1/f) + W_p/m_s \quad (2.5)$$

Replacing H_1 in Q_g,

$$Q_g/m_r = H_5 - H_4 f + H_3(f-1) - W_p/m_s \quad (2.6)$$

$$Q_a/m_r = H_3(f-1) + H_7 - H_4 f \quad (2.7)$$

$$Q_c/m_r = H_5 - H_6 \quad (2.8)$$

$$Q_e/m_r = H_7 - H_6 \quad (2.9)$$

Now that we have Q_g and Q_a , we can calculate the value of coefficient of performance.

$$\text{COP}, \eta = Q_e/(Q_g + W_p) \quad (2.10)$$

$$\text{But } W_p << Q_g \text{ and hence COP} = Q_e/Q_g \quad (2.11)$$

2.8 Sample calculation of COP for H_2O + [EMIM] [TFA]

I have used Figure 3.4 as a reference for my calculation.

Basis:
100 ton of refrigeration, then Q_e = 351.7 kW
T_e= 5 ºC, T_a=10 ºC, T_g=105 ºC and T_c=50 ºC

Required Information: - C_p of water = 4.187 kJ/kg-K , C_p of [EMIM] [TFA] = 1.45 kJ/kg-K

For finding out absorber and generator pressure, we have to find out the saturation pressure of water at 5 ºC and 50 ºC using Antoine equation, which is as follows.

$P_e = P_a$=0.87 kPa and $P_c = P_g$=12.34 kPa

Doing energy balance around the evaporator,

$$m_r (H_1 - H_{10}) = Q_e \quad (2.12)$$

From the enthalpy data of saturated steam,

H_1 = enthalpy of saturated vapor at 5 ºC = 2511 kJ/kg

H_{10} = enthalpy of saturated liquid at 5 ºC = 21 kJ/kg

From (2.12),

m_r = 0.141 kg/s

Now, we have to find the composition of absorber solution with the tabulated data given in the appendix **[12]**. From the table, we have to find out x_f at 0.87 kPa and 10 ºC.
By interpolating b/w 0.77 kPa and 1.07 kPa at 10 ºC, we have x_f = 0.302 and hence x_a=0.698.

Now to calculate generator solution composition we have to find out the value of x_f at 12.34 kPa and 105 ºC **[12]**. Following the same procedure as above, we have x_f= 0.037 and x_g=0.963.

Doing mass balance around the generator or absorber,

$$(m_s - m_r)x_g = m_s x_a$$

$$\Rightarrow m_s/m_r = x_g/(x_g - x_a) = f \quad (2.13)$$

Mass flow ratio, $f = m_s/m_r = x_g/(x_g - x_a)$ =3.63

$\Rightarrow m_s$ = 3.63x0.141=0.512 kg/s

$\Rightarrow m_s - m_r$= 0.512-0.141=0.371 kg/s

Now, C_{p1} = C_p of absorber solution = ((1.45x0.698) + (4.187x0.302)) = 2.27 kJ/kg-K
Then, C_{p2} = C_p of generator solution = (1.45x0.963) + (4.187x0.037)) = 1.55 kJ/kg-K

For Energy Balance around the heat exchanger in the Figure. 3.4,

$$m_s C_{p1}(T_4 - T_3) = (m_s - m_r)C_{p2}(T_{11} - T_{12}) \quad (2.14)$$

Let us assume that $(T_4 - T_3) = 30$ ºC
On putting the required values in (2.14),

$(T_{11} - T_{12})$ = 60 ºC
⇨ 105ºC - T_{12} = 60 ºC
⇨ T_{12} = 45 ºC

Now, for heat duty of the absorber,

$$Q_a = m_2H_2 - m_1H_1 - m_{13}H_{13} \quad (2.15)$$

We have, H_2= enthalpy of weak solution at 10 ºC obtained by interpolating between $x_f = 0.243$ and $x_f = 0.420$ = -10.57 kJ/kg [12]
H_{13}= enthalpy of strong solution at 45 ºC = 58.155 kJ/kg [12]
$m_2 = m_s = 0.512$ kg/s
$m_1 = m_r = 0.141$ kg/s
$m_{13} = m_s - m_r = 0.371$ kg/s
Putting the required details in (2.15),

Q_a= - 422.5 kW

For heat balance around generator,

$$m_4H_4 + Q_g = m_6H_6 + m_{11}H_{11} \quad (2.16)$$

We have, H_6=enthalpy of superheated water at 105 ºC=2696.52 kJ/kg
H_{11}=enthalpy of strong solution at 105 ºC=155.92 kJ/kg
H_4=enthalpy of weak solution at 40 ºC=60.68 kJ/kg
$m_4 = m_s = 0.512$ kg/s
$m_6 = m_r = 0.141$ kg/s
$m_{11} = m_s - m_r = 0.371$ kg/s
Putting all the required values in (2.16),

$Q_g = 406.98$ kW

For energy balance around the condenser,

$$Q_c = m_r(H_7 - H_8) \quad (2.17)$$

From steam table data,
H_7=enthalpy of saturated vapor at 50 ºC=2592 kJ/kg
H_8=enthalpy of saturated liquid at 50 ºC=209.3 kJ/kg

Putting all the required values in (2.17),

$$Q_c = 336 \text{ kW (heat rejected)}$$

For Pump work,

$$W_p = m_s(\Delta H) = m_s(12.34 - 0.87)/\rho$$

Here, ρ =density of the weak solution= ((0.302*1) + (0.698*1.324)) x 10^3

$\Rightarrow$ $\rho = 1.226 \times 10^3$ kg/m^3

So, W_p= 4.89 W

$\Rightarrow$ W_p=0.00489 kW

Ignoring the value of W_p (as it is very small), we have

$$COP = Q_e/Q_g = 0.864$$

CHAPTER 3

Simulation and Analysis of Absorption Refrigeration Cycle

3.1 Introduction to Aspen Plus

Aspen ONE is Aspen-Tech's comprehensive set of software solutions and professional services designed to help process companies achieve their operational excellence objectives. It leverages the value of simulation models to help process companies increase operational efficiency and profitability across their global enterprise. Aspen-one cover four major field as shown in Figure 3.1 which are Chemical, Energy, Polymer, Pharmaceuticals.

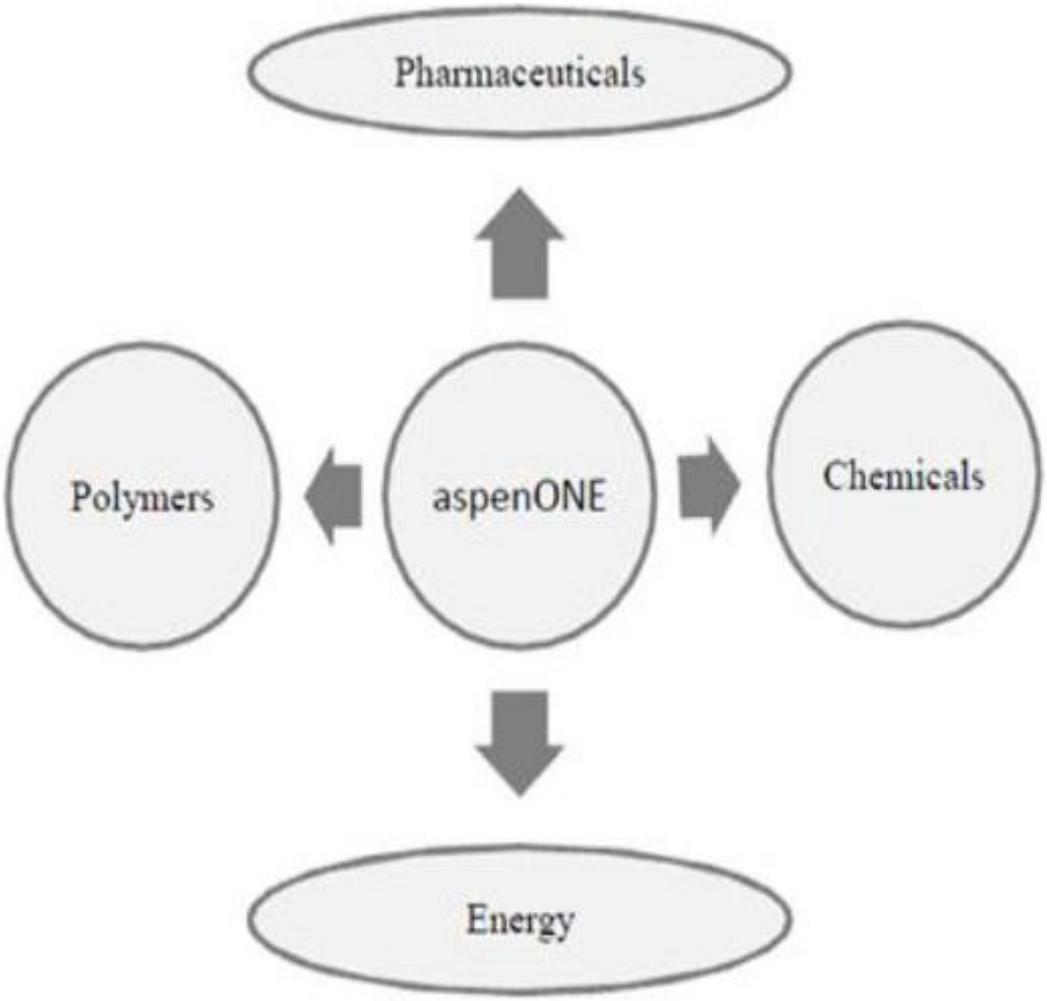

Figure 3.1 Industries and business areas of Aspen ONE

3.1.1 Aspen one engineering

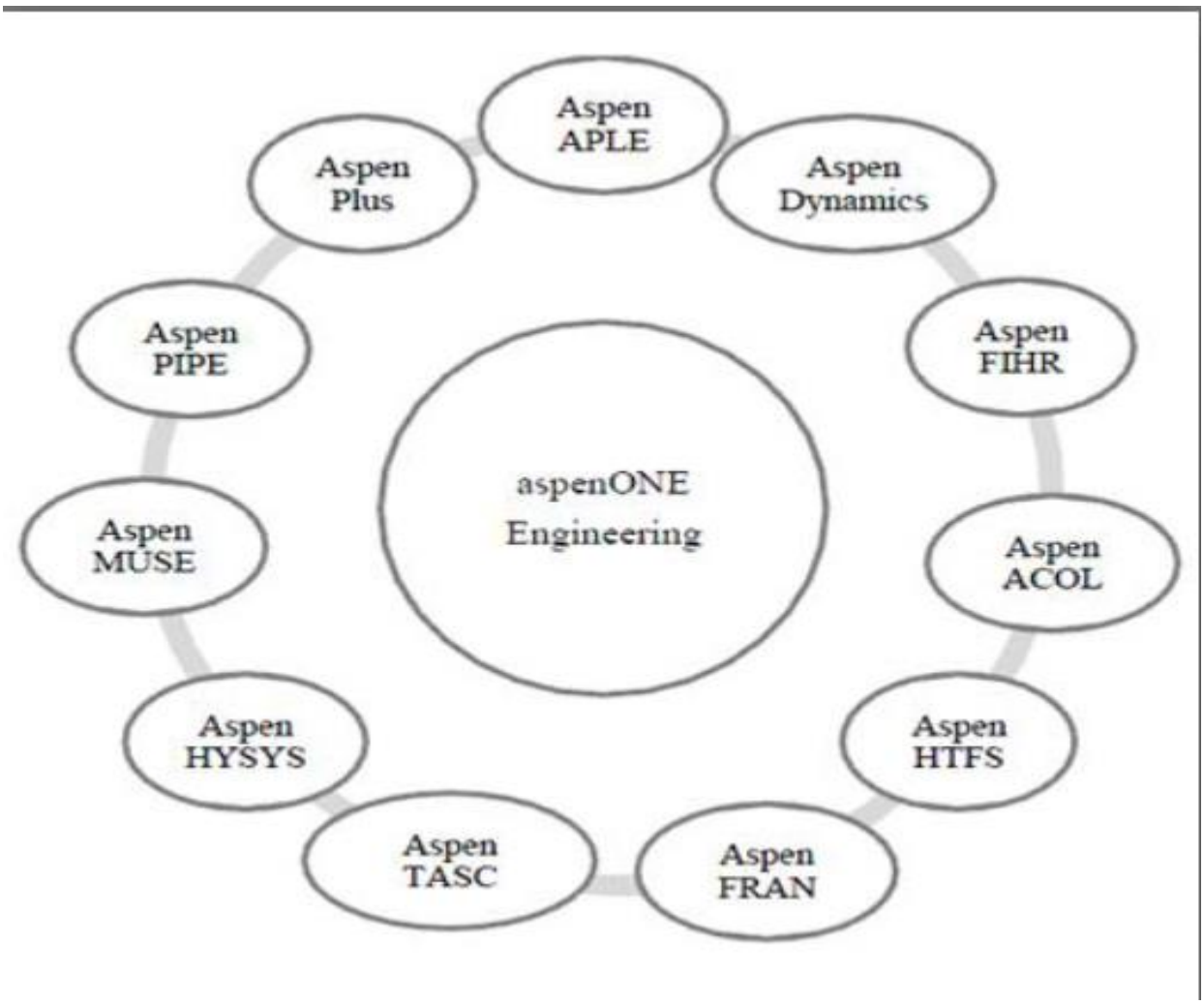

Figure 3.2 Aspen One Engineering Classification

3.1.2 Aspen Plus

Aspen Plus is a market-leading process modelling tool for conceptual design, optimization, and performance monitoring for the chemical, polymer, specialty chemical, metals and minerals, and coal power industries. Aspen plus is a software package designed to allow a user to build a process model and then simulate the model without tedious calculations.

3.2 Equation of state

In physics and thermodynamics, an equation of state is a relation between intensive and extensive state of the system. More specifically, an equation of state is a thermodynamic equation describing

the state of matter under a given set of physical conditions. It is a constitutive equation which provides a mathematical relationship between two or more state functions associated with the matter, such as its temperature, pressure, volume, or internal energy. Equations of state are useful in describing the properties of fluids, mixtures of fluids.

3.3 Addition of components

Water and [EMIM] [TFA] are chosen as the components for the absorption refrigeration cycle simulation using aspen plus.

3.4 Guidelines for choosing property methods

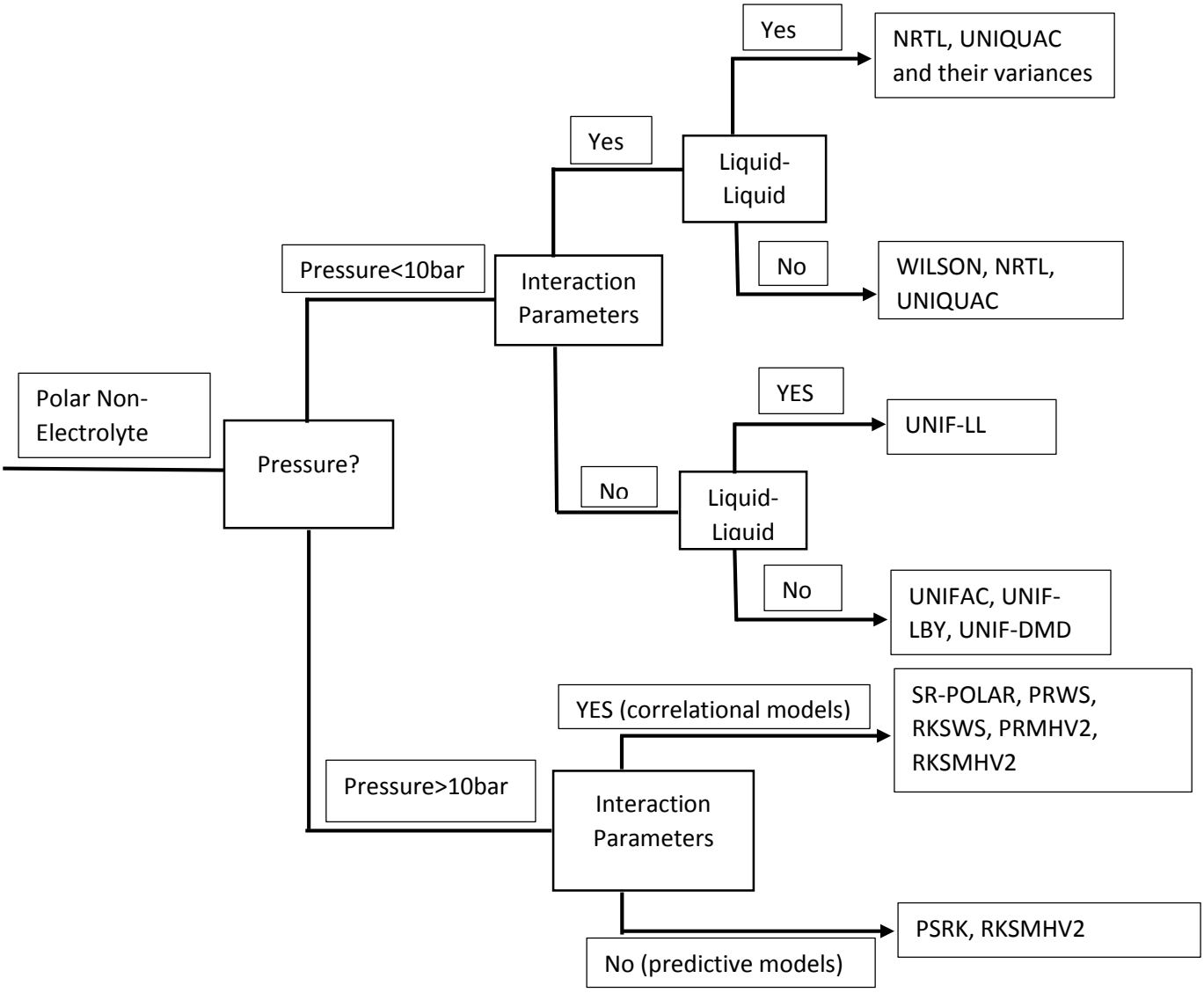

Figure 3.3 Guidelines for choosing property method for polar non-electrolyte systems

Aspen Plus contains various property packages, but for absorption refrigeration cycle for H_2O and [EMIM] [TFA] based working pairs, we will be using NRTL property method, which is quite obvious as seen from the Figure 3.3.

3.5 Modelling in Aspen Plus

Modeling in ASPEN plus is based in taking a process and breaking it down into more simple components, also known as "blocks".

- ✓ **State point 1** refers to the refrigerant liquid which is at a saturated state and needs to evaporate.

- ✓ **The evaporator** is modelled as a heater block using the steam NBS property method. The inputs to the model were zero pressure drop and a vapor quality of 1 at the exit. Steam NBS is a FORTRAN90 library which computes the various physical properties of water, related to temperature, pressure and density.

- ✓ **The absorber** is modeled as a heater block with two inputs, the exit of the evaporator and the exit of the solution valve. The inputs are zero pressure drop and zero vapor quality.

- ✓ **Desorber or generator** is modelled by using a flash block which separates the vapor from the liquid. Along with the flash block a heater block is used to provide the heat needed for generating the refrigerant, which is equivalent to the waste heat energy. Its inputs are zero pressure drop and outlet temperature (based on the temperature of the heat input into the cycle).

- ✓ **The condensers** were modeled as heater blocks. Assuming no pressure drop, the only input necessary is to specify a vapor quality of 0 at the exit.

- ✓ **A solution heat exchanger (SHX)** is modelled as two heaters joined by heat stream to indicate that the heat rejected on the hot side was to be added to the cold side. Heat is transferred from state 10 (the hot side inlet) to state 3 (the cold side inlet), resulting in states 11 (the hot side exit) and 4 (the cold side exit). Assuming no pressure drop, the only two unknowns are the exit temperatures. One unknown was described by assuming a heat exchanger effectiveness, defined below.

$$\text{Effectiveness, } e = (T_{11} - T_{12})/(T_{11} - T_3) \text{ (From Figure. 3.4)}$$

- ✓ **Pumps** are used between states 2 and 3. Pumps require only one input, the exit pressure. The default value of 100% efficiency was used because of the negligible effect on the

overall cycle of picking a different efficiency (the pump work is several orders of magnitude smaller than the heat duties of other components).

Based on the blocks we have used, the complete flow sheet for the absorption refrigeration cycle will be as follows:

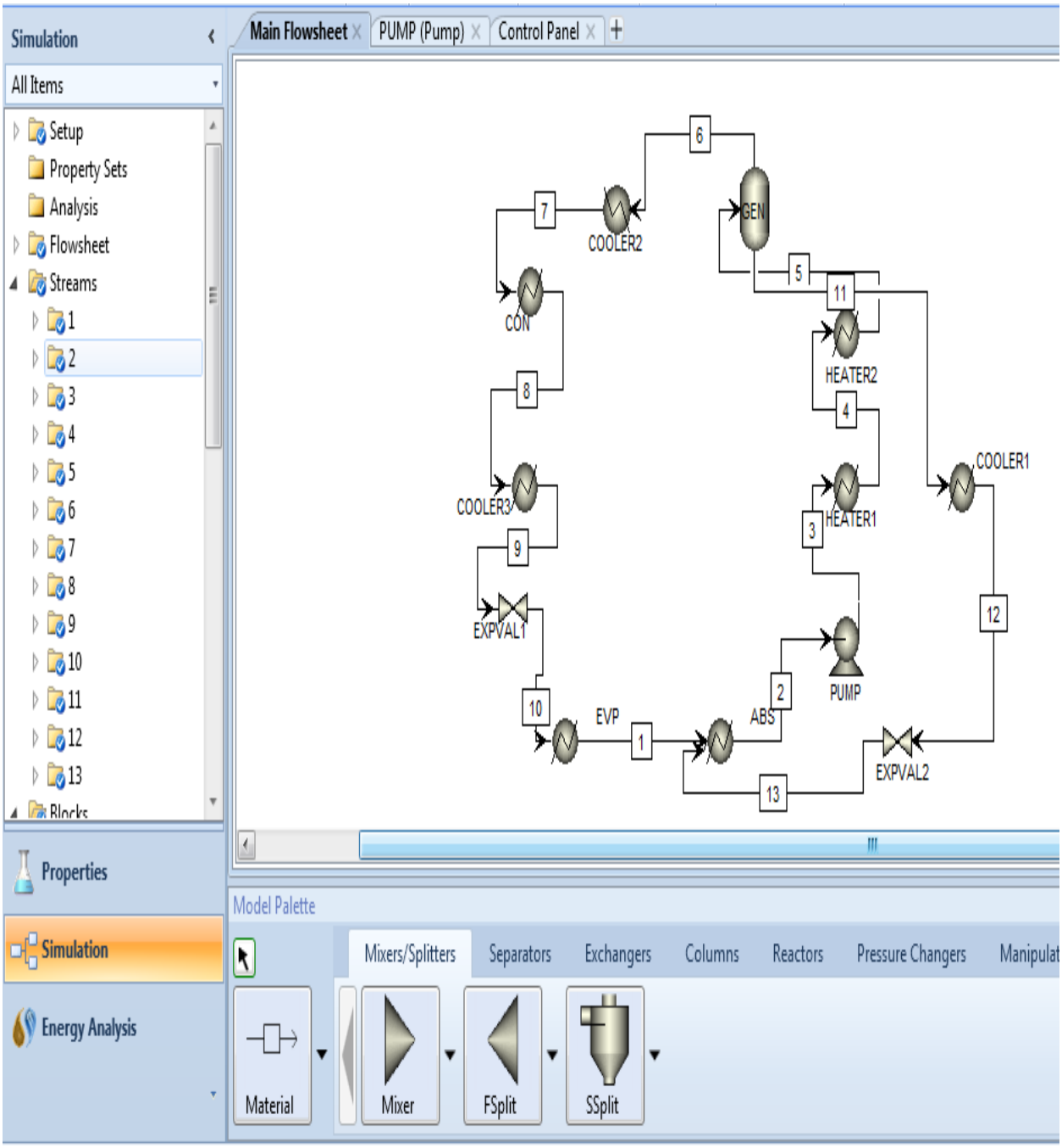

Figure. 3.4 Complete flow sheet of Absorption refrigeration cycle in Aspen Plus

3.6 Error analysis

On carrying out above simulation in aspen plus, we got the following error message as follows:

i) VAPOR PRESSURE MODEL PL0XANT HAS MISSING PARAMETERS.

ii) PLXANT/1ST ELEMENT (DATA SET 1) MISSING FOR COMPONENT C_8H_{11}-01.

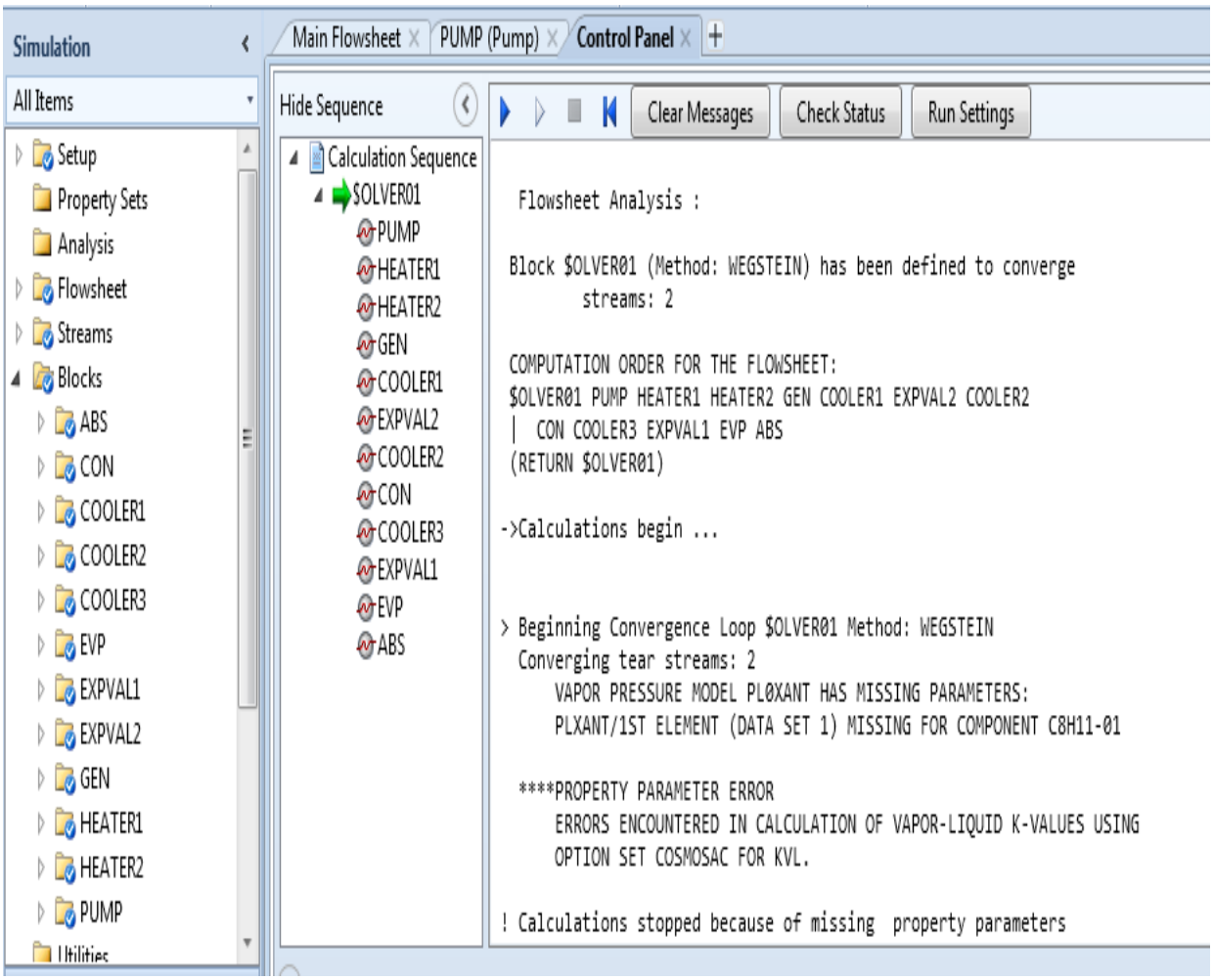

Figure. 3.5 Error message in Aspen Plus

The problem here is that C_8H_{11}-01 exists in the Aspen PLUS database but is missing the necessary PLXANT data. This has to be supplied by Aspen PLUS. Since it exists in both Aspen PLUS and OLI, our routines do not attempt to provide any data. This is really an Aspen PLUS issue.

3.7 Manual simulation

As you have already seen that our simulation did not run due to severe issue with Aspen Plus, we switched over to the tedious manual simulation. In manual simulation we calculated the value of COP for the system and then we changed the state conditions to optimize the value of COP.

3.7.1 Change in evaporator temperature

Table 3.1: COP calculation table for T_e = 5 ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_e=40ºC	T_g=105ºC	T_c=50 ºC	56.65	0.325
P_e=0.87 kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=1115.5kW	Q_g=1100kW	Q_c=336kW		
x_f=1	x_a=0.946	x_g=0.963	x_f=1		

Table 3.2: COP calculation table for T_e =10 ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=10ºC	T_a=40ºC	T_g=105ºC	T_c=50 ºC	30.09	0.468
P_e=1.22kPa	P_a=1.22kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=354.3kW	Q_a=774.5kW	Q_g=756.3kW	Q_c=336kW		
x_f=1	x_a =0.931	x_g =0.963	x_f=1		

Table 3.3: COP calculation table for T_e =25ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=25ºC	T_a=40ºC	T_g=105ºC	T_c=50 ºC	8.37	0.743
P_e=3.16kPa	P_a=3.16kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=349.3kW	Q_a=482.8kW	Q_g=469.5kW	Q_c=336kW		
x_f=1	x_a =0.848	x_g =0.963	x_f=1		

3.7.2 Change in generator temperature

Table 3.4: COP calculation table for T_g=105ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=105ºC	T_c=50 ºC	3.63	0.864
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=422.5kW	Q_g=407kW	Q_c=336kW		
x_f=1	x_a =0.698	x_g =0.963	x_f=1		

Table 3.5 COP calculation table for T_g =90ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=90ºC	T_c=50 ºC	3.89	0.878
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=422.5kW	Q_g=406.7kW	Q_c=336kW		
x_f=1	x_a =0.698	x_g =0.939	x_f=1		

Table 3.6: COP calculation table for T_g=75ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=75ºC	T_c=50 ºC	4.56	0.887
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=418.3kW	Q_g=402.5kW	Q_c=336kW		
x_f=1	x_a =0.698	x_g =0.894	x_f=1		

3.7.3 Change in absorber temperature

Table 3.7: COP calculation table for T_a=10ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=105ºC	T_c=50 ºC	3.63	0.864
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=422.5kW	Q_g=407kW	Q_c=336kW		
x_f=1	x_a =0.698	x_g =0.963	x_f=1		

Table 3.8: COP calculation table for T_a=25ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=25ºC	T_g=105ºC	T_c=50 ºC	13.19	0.667
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=543.33kW	Q_g=527.63kW	Q_c=336kW		
x_f=1	x_a =0.89	x_g =0.963	x_f=1		

Table 3.9: COP calculation table for T_a=40ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=40ºC	T_g=105ºC	T_c=50 ºC	56.65	0.325
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=1115.2kW	Q_g=1100kW	Q_c=336kW		
x_f=1	x_a =0.946	x_g =0.963	x_f=1		

3.7.4 Change in condenser temperature

Table 3.10 COP calculation table for T_c=50ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=105ºC	T_c=50 ºC	3.63	0.864
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=12.34kPa		
Q_e=351.7kW	Q_a=422.5kW	Q_g=407kW	Q_c=336kW		
x_f=1	x_a =0.698	x_g =0.963	x_f=1		

Table 3.11 COP calculation table for T_c=40ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=105ºC	T_c=40 ºC	3.51	0.869
P_e=0.87kPa	P_a=0.87kPa	P_g=12.34kPa	P_c=7.36kPa		
Q_e=351.7kW	Q_a=423.5kW	Q_g=410.65kW	Q_c=339kW		
x_f=1	x_a =0.698	x_g =0.976	x_f=1		

Table 3.12 COP calculation table for T_c=60ºC

Evaporator	Absorber	Generator	Condenser	Flow ratio	COP
T_e=5ºC	T_a=10ºC	T_g=105ºC	T_c=60 ºC	3.83	0.857
P_e=0.87kPa	P_a=0.87kPa	P_g=19.89kPa	P_c=19.89kPa		
Q_e=351.7kW	Q_a=435.58kW	Q_g=416.39kW	Q_c=332.54kW		
x_f=1	x_a =0.698	x_g =0.945	x_f=1		

CHAPTER 4

System Analysis and Economic Feasibility

As per the tables presented in the chapter 3, the performances of ARS has been analyzed.

4.1 System analysis

1) Value of COP decreases with increase in T_a

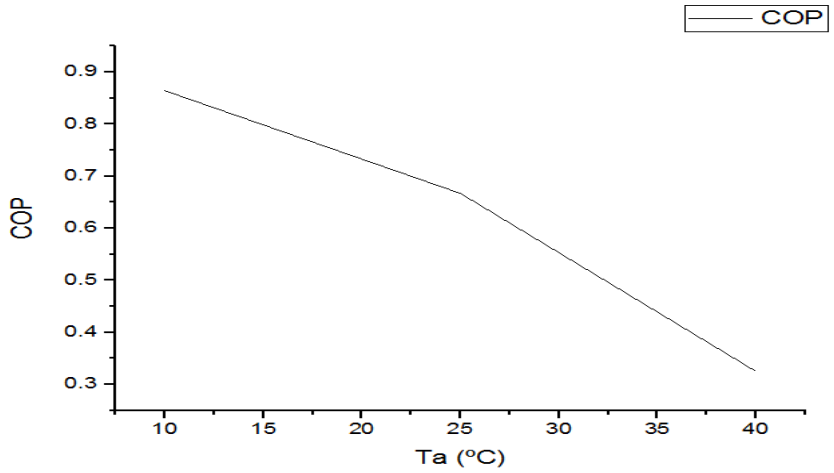

Figure 4.1 Variation of COP with T_a

2) Value of COP decreases with increase in T_c

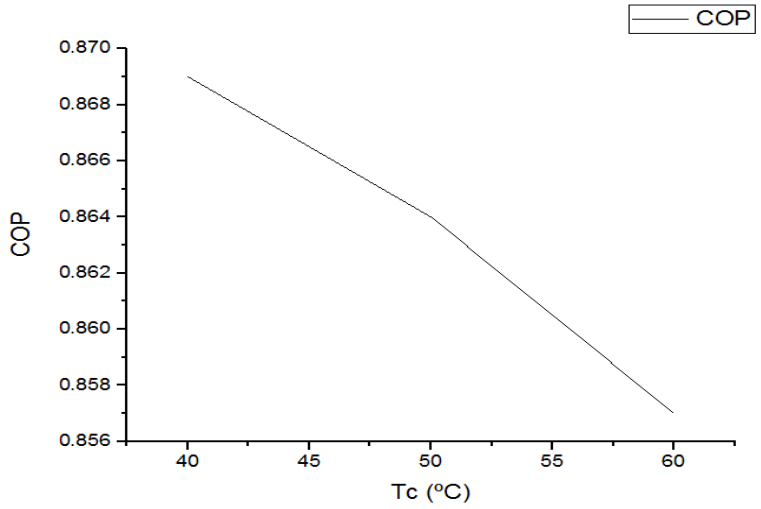

Figure 4.2 Variation of COP with T_c

3) Value of COP increases with increase in T_e

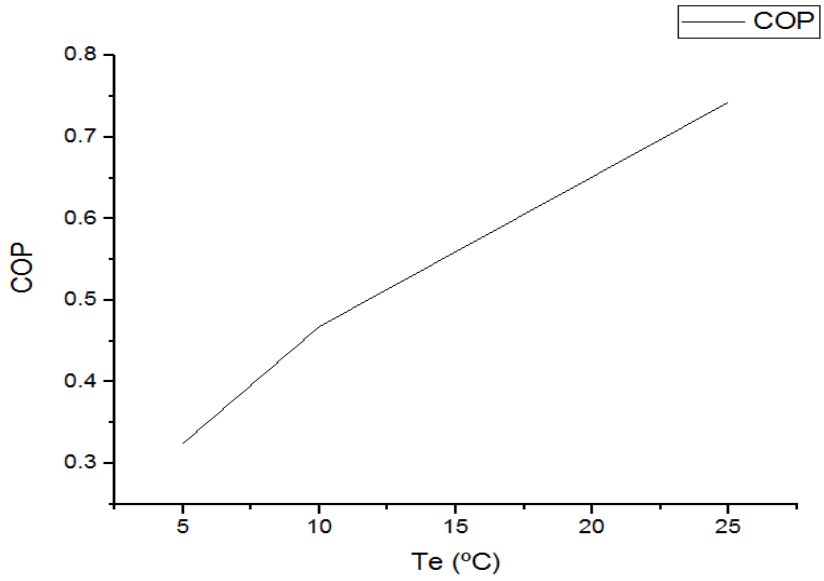

Figure 4.3 Variation of COP with T_e

4) Value of COP decreases with increase in T_g

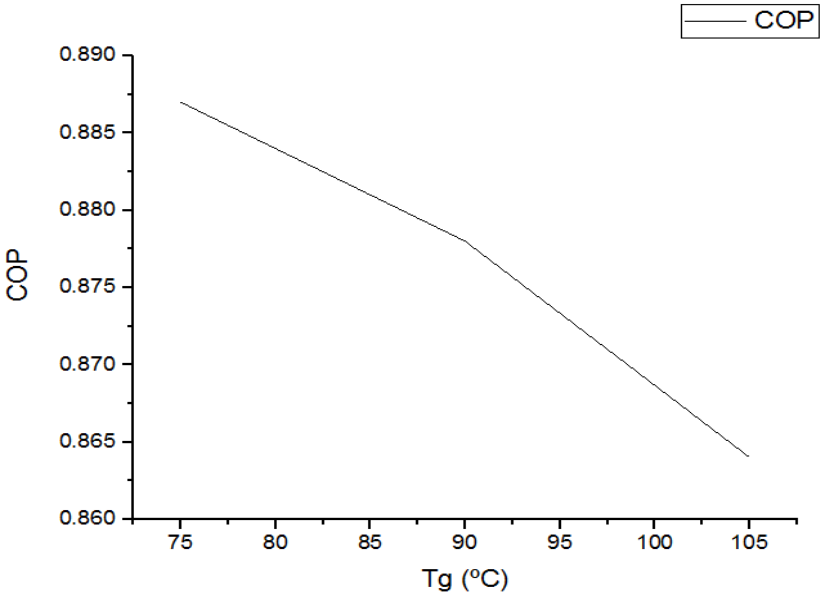

Figure 4.4 Variation of COP with T_g

4.2 Cost estimation

Basis: Let us consider the vapor absorption refrigerator with the following specifications as our reference system for cost analysis: T_e= 5ºC, T_a=10ºC, T_g=75ºC and T_c=50ºC.

Let us assume that the absorption refrigerator works for 8hrs a day for 300 days in a year.

Electricity Tariff:

Table 4.1 Cost per unit of Electricity Consumption

Electricity Consumption in kWh	Cost per unit in INR
0-100	5.10
101-300	6.20
>301	6.90

Fixed Cost of H_2O + [EMIM] [TFA] based working pairs = Rs 3, 18,000/-

Let, the lifetime of the absorption refrigeration cycle is 10 years.

Annual fixed cost for absorption refrigeration cycle = Rs 31,800/-

Operating Cost of Refrigerator:-

Heat duty of evaporator for 1.5 ton of refrigeration capacity= 5.27 kW

Electricity consumed in units by evaporator per year= 5.27*8*300= 12648kWh

Heat duty of absorber =6.27kW

Electricity consumed in units by absorber per year= 6.27*8*300= 15048kWh

Heat duty of generator =6.03kW

Electricity consumed in units by generator per year= 6.03*8*300= 14490kWh

Heat duty of condenser =5.208kW

Electricity consumed in units by condenser per year= 5.208*8*300= 12096kWh

Pump Duty per year=$7.335 \times 10^{-5} \times 8 \times 300$=0.17604kWh

Heat duty required for the ARS considered per year = Heat duty of the (generator + evaporator + pump) = 27,138 kWh

Extra Heat Duty Needed= Absorber heat duty- Generator heat duty= 0.24 kW

Consumption of electricity due to extra heat duty per year=0.24*8*300=576 kWh

Cost of extra heat duty per year=576*6.9= Rs 3974.4/-

Total Annual Cost= Annual Fixed Cost + Cost of extra heat duty=31,800+3974.4

⇨ Total Annual Cost= Rs 35774.4/-

- ✓ If we possess 27,138 kWh of thermal energy as a low grade energy at 75 ºC per year it will operate an absorption refrigeration system having 1.5 ton of refrigeration capacity on the basis of 8 hours per day for 300 days in a year.

- ✓ Moreover, in this process still lower grade energy of 15048kWh at 10 ºC in the absorber and 12096 kWh at 50 ºC in the condenser will be created.

- ✓ The annual cost of refrigeration for the H_2O + [EMIM] [TFA] system is Rs 35774.4/-

4.3 Comparison with conventional vapor compression refrigeration cycle

Total annual Cost for 1.5 ton of Vapor Compression Cycle = Rs 40,000/-

From the above calculation in section in 4.2,
Total annual Cost for 1.5 ton of Vapor absorption refrigeration cycle using H_2O+ [EMIM] [TFA] = Rs 35774/-

Profit for the absorption refrigeration system = 40,000 – 35774 = 4226/-

- ✓ Hence, with among the two types of refrigeration cycles, using ARS using H_2O+ [EMIM] [TFA] is having a profit of Rs 4226, which proves the potency of the absorption refrigeration cycle as it is utilizing the low grade heat at 75 ºC.

- ✓ Reduces the average global temperature by utilizing the waste heat.

- ✓ Restrict the combustion of fossil fuels, CO_2 emissions and the use of CFCs as well.

CHAPTER 5

Conclusions and Future Recommendations

This chapter summarizes the major conclusions from this research work and presents some much needed suggestions for future work.

5.1 Conclusions

- ✓ COP of the optimal absorption refrigeration cycle is coming out to be 0.887 under the optimal configuration of T_e= 5ºC, T_a=10ºC, T_g=75ºC and T_c=50ºC.

- ✓ The annual capital cost of the absorption refrigeration cycle using H_2O + [EMIM] [TFA] is coming out to be Rs 35780 and hence it makes a profit of Rs 4226 per year with reference to the vapor compression cycle.

- ✓ The H_2O + [EMIM] [TFA] system of 1.5 ton refrigeration capacity is utilizing 27,138 kWh of low grade energy at 75ºC and releases the same amount of low grade energy. This system not only helps in reducing the average global temperature but also reduces the use of fossil fuels and CO_2 emissions.

- ✓ ILs have many favorable properties which make them attractive for a number of applications. ILs have a negligible vapor pressure under normal operating conditions and have a large liquid working temperature range. Here, these novel compounds were investigated to improve the most sought after and energy efficient absorption refrigeration cycle.

- ✓ Major conclusions regarding the influence of evaporator, generator, absorber and condenser temperature on the value of COP were drawn. It was shown that the IL and water systems have a higher coefficient of performance than the current technology, LiBr and water, and the coefficient of performance increases with increasing excess enthalpy.

- ✓ In fact, the water + [EMIM] [TFA] system shows a 6.48 % improvement of the coefficient of performance over the current technology. Absorption refrigeration is a great application for ILs and should be used when a low grade heat source is available.

5.2 Future recommendations

Great progress has been made on the absorption refrigeration cycle through a thermodynamic analysis and calculations of the coefficients of performance. But still there are certain roadblocks that needs to be focused. Further research using IL+ water as working pair is recommended for absorption refrigeration system, which includes,

1) Generation of thermo physical data is extensively needed for the development of such kind of application.

2) Rigorous design and economic analysis for IL+ water based absorption refrigeration system is required.

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